Research paper

Biomass production of maize (*Zea mays* L.) cropping in exceptionally advantageous conditions in central Wielkopolska (Poland)

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ABSTRACT

The net primary production (NPP) of a maize (*Zea mays* L.) field in Poland was estimated, in weather conditions close to those predicted for the middle of the century, given the ongoing changes in the global climate. The average temperature during the maize cropping period (May–September) was 16.9 °C and the total rainfall was 392.5 mm. In such conditions maize NPP reached exceptionally high levels – 3.29 kg m^{-2}, on average. Such an unprecedented level of NPP was achieved as a result of climatic conditions favourable to C4 photosynthesis. The above-ground biomass of maize made up 78% of the total NPP, while the below-ground production was only 7.7% of NPP; weed production was very low, only slightly exceeding 8 g m^{-2} 14.5% of the total NPP consisted of dying and decomposing biomass. Conducted under conditions close to those foreseen for the mid-21st century, this field study enabled NPP levels as well as future relations between plants in different photosynthetic pathways to be predicted. The expected changes in climatic conditions offer good prospects for maize cropping. The beneficial relationship between the above- and below-ground parts of maize and the low percentage of dying and decomposing biomass mean that this plant can be used for silage or biofuel production.

1. Introduction

The magnitude of the net primary production (NPP) of the earth's ecosystem for the period 1982–1999, as reviewed by Ref. [1], indicates an increasing level of NPP on a global scale. This has been confirmed by an analysis of changes in NPP of grassland ecosystems in the northern hemisphere [2]. According to these analyses, NPP increased markedly in the second half of the 20th century. There is a major factor causing this increase – shift of the atmospheric CO_2 concentration. According to [3], the content of CO_2 in the atmosphere increased from 320 to 350 mol mol^{-1} within 30 years (1950–1980). After [4], the value of CO_2 concentration is forecasted to reach about 505 $\pm$ 27 μmol mol^{-1} over the next 35 years, and [5] predict that in the end of 21st century the level of CO_2 will reach 700 mol mol^{-1}. Growing level of CO_2 entails the increase in global temperature by 1.5–4.5 °C. Since the mid 19th century, the five warmest years have occurred in 1990s [6]. However, because the system of interrelated factors (CO_2, temperature, water and nutrient availability) is complex, it is difficult to predict the direction that changes in NPP are likely to take [5]. NPP could even decline as these global changes take place, at least in some regions of the world, owing to deteriorating humidity conditions [1,8]. On the other hand, many papers have shown that unfavourable changes in soil humidity can be mitigated by appropriate modification of the landscape structure [2,9–12].

The ongoing climate changes in Poland are becoming visible, in a gradual increase in average air temperatures. Apparently most models imply a simultaneous increase in annual precipitation [13–15], but always with a shift of rainfall frequency towards the cooler months. Such changes cause the hygrothermic conditions during the growing season to deteriorate. A similar trend has been found in the neighbouring state of Brandenburg [16,17].

Studies of the effects of climate change on the magnitude of NPP have been carried out since the 1960s [18–25]. Most models, supported by experimental data, assume that NPP will increase concurrently with global climate change [26–29]. On the other hand, field research has shown that water or nitrogen deficits can limit the positive effects of temperature and CO_2 concentration on the magnitude of NPP. [30–34]. Hence, some authors have affirmed that global climate change has no impact on the magnitude of NPP [8,23,31,35], or that its influence is negative [31,35–37].

It should be highlighted that the causes of the potential increase or decrease of NPP are different for plants with different photosynthetic pathways. For C3 plants, increasing atmospheric CO_2 concentrations will play a major role [20,33,38–43]. In contrast, the biomass production of C4 plants is only slightly dependent on CO_2 levels [44]; indeed, rising CO_2 concentrations in the atmosphere can even reduce this production [45]. In the light of the above, therefore, temperature increases will be crucial [46]. Furthermore, although changes in humidity

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conditions will not seriously affect C4 plants, the deterioration of hygrothermic conditions will mainly limit the biomass production of C3 plants. Thanks to the double mechanism of carbon dioxide fixation in C4 plants, their stomatal conductance and transpiration rates are lower. Consequently, they have a better water use efficiency index (WUE) at both the single plant [47] and the ecosystem level [34,48,49]. They also have a lower requirement for nitrogen [50,51]. Finally, the balance can move towards the dominance of both C3 and C4 plants, depending on how the relevant factors are interrelated. Such a concept is supported by a study from Inner Mongolia (China), which demonstrated that the proportion of C4 plants in that region decreased by about 10% as a result of increasing CO_2 level, preferring C3 plants. Simultaneously, the area occupied by C4 plants spread about 1° northwards, as a result of the increase in temperature [52].

The most common crop worldwide with a C4 photosynthetic pathway is maize. In Poland, too, it is by far the most popular C4 crop, cultivated mainly as silage substrate for fodder. However, the potential increase of its role in the crop structure with ongoing global climate change creates the opportunity to use it for biofuel production: the same silage is a potential substrate for biogas production [53–55]. It can also be used for producing ethanol from a lignocellulose substrate, using whole biomass [56,57]. Such a process permits the use of the entire above-ground biomass of maize in the form of bagasse, in the same way as sorghum is used [58]. Technologies enabling economically viable production of ethanol from different kinds of bagasse are just developed [59].

The present paper discusses a study of the NPP of maize (*Zea mays* L. **v.** Vasili) in central Wielkopolska (west Poland) conducted in field conditions. Especially propitious conditions, similar to those predicted by the progress in global climate change [17,60], occurred in 2012. This afforded a unique opportunity for undertaking the main task of the study: predicting how maize could adapt to forthcoming changes.

2. Materials and methods

The study was conducted in 2012, near the village of Turew, 52°03′56″N, 16°48′01″ E, in the province of Wielkopolska (Greater Poland), one of the warmest regions of the country. Both temperature and rainfall that year were particularly advantageous for C4 plants. The mean temperature during the maize harvest was 1.2 °C higher than the historical mean for the study area, while rainfall during this period was close to the historical mean [61].

This survey was carried out in a field 26.11 ha in area. Shelterbelts adjoined the field to the west and south. This layout of the landscape elements was responsible for considerable variation in soil moisture, which was particularly pronounced in that part of the field (5.7 ha) next to the shelterbelts. Hence, it was possible to test the impact of landscape structure on microclimatic conditions. This particular area of the field was therefore chosen for the survey (Fig. 1). The soil in the field was Hapludalfs, formed on slightly loamy sand [62]. Agricultural practices were typical of maize cropped for silage (Table 1).

The experimental area (150 × 80 m, 52°03′58″N; 16°48′06″E) was delineated in the field (Fig. 1) where 100 sample plots each 16 m^2 in area for estimating NPP and measuring soil properties were established. These plots were located at distances of 15, 30, 50, 100 and 150 m from the western (adjoining the shelterbelt) edge of the field, with 20 plots at each distance (Fig. 2). This sampling design was based on earlier studies of maize NPP in the diverse farming landscape near Turew [2].

The climate data (air temperature, rainfall and wind direction) were obtained from the meteorological station of the Institute for Agricultural and Forest Environment PAS, located 1 km SE of the study area. Soil humidity and temperature were measured at 25 points (five at each distance from the shelterbelt listed above) in the experimental area. These measurements were made throughout the growing season at two-week intervals, each time at all 25 sites. The temperature was measured with a soil thermometer at a depth of 5 cm (each time

Fig. 1. Layout of the study field.

Table 1
Agricultural practices used on the studied field.

Date	Agricultural practice		Dose
2011-08-21	Skimming		–
2011-09-12	Herbicide: Avans 360 S L (with adjuvant)		2.03 $dm^3 ha^{-1}$
	Chicken manure		9.96 Mg ha^{-1}
2011-09-28	Tillage (plowing unit)		–
	Forecrop for green manure (mustard) sowing		15.32 kg ha^{-1}
2012-03-19	Fertilizer: Kali Korn: (K_2O - 40%, MgO - 6%, SO_3 - 12%, Na_2O - 4%)		240 kg ha^{-1}
2012-03-26	Herbicide: Avans 360 S L (with adjuvant)		2.76 $dm^3 ha^{-1}$
2012-04-15	Herbicides:	Guardian 664 Se	1.88 $dm^3 ha^{-1}$
		Klinik 360 S L	2.49 $dm^3 ha^{-1}$
	Nitrogen fertilizer: urea		76.60 kg ha^{-1}
	Maize (varietas Vasili) sowing		1 000 000·ha^{-1}
2012-05-16	Herbicides with adjuvant:	Afalon 450 S C	2.30 $dm^3 ha^{-1}$
		Inovate 240 Sc	0.15 $dm^3 ha^{-1}$
		Mustang 306 Se	0.38 $dm^3 ha^{-1}$
2012-05-25	Trace Elements:	Adob Cu (Cu – 4.4%, N-NO_3 – 2.0%)	0.69 $dm^3 ha^{-1}$
		Adob Mn (10%)	0.38 $dm^3 ha^{-1}$
		Adob Zn (10%)	0.69 $dm^3 ha^{-1}$
		Dot-67 (B_2O_3 67.00%. Na_2O 14.00%)	1.15 kg ha^{-1}
		Mg SO_4	5.02 kg ha^{-1}
	Nitrogen fertilizer: urea		11.49 kg ha^{-1}
2012-09-18	Harvest		–
Agricultural yield			**39.06 Mg ha^{-1}**

Fig. 2. Organization of the study area: 1, 2, 3, 4 – sampling times; a, b, c, d, e - replicates.

between 11:30 and 12:00 h). Humidity was estimated using the weighing and drying method. The samples (five at each distance) were taken with $100 \, cm^3$ Kopecki cylinders at the same time as the temperature measurements.

NPP was assessed using direct methods, widely applied in studies carried out at small spatial scales [63–65]. The material from the 25 sample plots (five at each distance from the shelterbelt) was taken each time from one $0.25 \, m^2$ square and four $0.09 \, m^2$ squares designated for sampling the plant material. The bigger square ("A") was used for estimating the standing crops of living plant biomass (G), dead biomass (D) and litter (L). The material was collected four times during the cropping season: on June 19th, July 9th, August 1st and September 8th. All plants, both maize and weeds, were cut, after which the litter was collected manually. The smaller squares (a, b, c, d) were used for calculating the - ΔD (the increment of dead plant biomass and litter). This was done at two-week intervals, throughout the cropping season, starting from June 19th. Dead plant material, including dead biomass (detached with scissors) and litter, was collected according to Łomnicki's [66] modification of Wiegert-Evans's [67] method, but because of the high sampling frequency, differential equations were not used [63].

The biomass of below-ground parts was estimated twice during the growing season (on July 10th and September 9th) by collecting soil monoliths with a $78.5 \, cm^2$ soil sampler down to 30 cm depth. The monoliths were taken in the sample plots (five at each distance from the shelterbelt) in square "A" immediately after the above-ground parts had been gathered. On the first date five monoliths were collected for calculating the below-ground biomass, and five for assessing their decomposition. The latter were returned to the soil in chiffon bags and collected the next time in order to estimate the biomass of roots that had not decomposed. On the second date only monoliths for assessing the standing crop roots were collected [68].

The above-ground plant material was transported to the laboratory in paper bags, divided manually into dead and living parts of maize, weeds (not separated into individual species) and litter, and then the living parts of maize into stems, leaves and generative organs (panicles and cobs). The below-ground parts were transported in plastic bags, stored at 4 °C, rinsed on 0.25 mm sieves and divided manually into dead and living parts. The whole plant material and the litter were dried at 80 °C to constant mass and weighed accurate to 0.01 g. All biomasses are expressed as dry mass. Biomass production and decomposition of dead matter were calculated using the formulas given in Table 2.

Table 2
Formulas used for calculation of net primary production of maize field.

Calculated value	Formula
Decomposition of above-ground parts	$M = \Sigma(D_{t+1}-D_t) + \Sigma\Delta D_{t-t+1}$
Death of above-ground parts	$D = \Sigma\Delta D_{t-t+1}$
Production of above-ground parts	$P_a = \Sigma(G_{t+1}-G_t) + D$
Decomposition of below-ground parts	$X = (R + V)_{t1} - (R^* + V^*)_{t1}$
Production of below-ground parts	$P_b = R_{t2} + (V_{t2}- V_{t1}) + X$
Decomposition of below-ground parts	$X = (R + V)_{t1} - (R^* + V^*)_{t1}$
Production of below-ground parts	$P_b = R_{t2} + (V_{t2}- V_{t1}) + X$

Where:

ΔD_{t-t+1} - increase of dead parts and litter during the interval between consecutive estimates (two-week intervals).

D_t –- dead parts and standing crop litter collected in time t.

D_{t+1} – dead parts and standing crop of litter collected in time t+1.

G_t – living plant biomass of standing crop collected in time t.
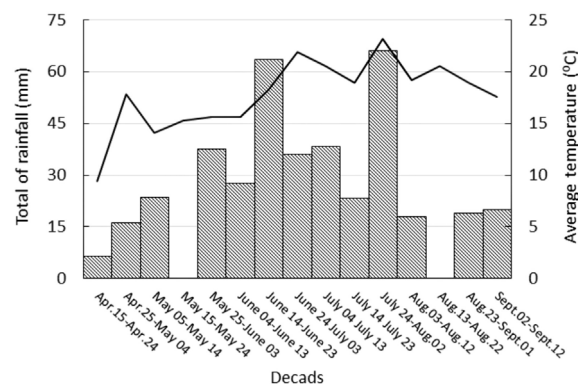
G_{t+1} - living plant biomass of standing crop collected in time t+1.

R – biomass of living below-ground parts.

V– biomass of dead below-ground parts.

R* biomass of living below-ground parts incubated in soil.

V* biomass of dead below-ground parts incubated in soil.

Fig. 3. Average decade temperature rainfall and sum of decade rainfall during maize cropping (April 15 – September 12, 2012).

3. Results

3.1. Climate and soil conditions

During the maize vegetation period (April 15th – September18th) the average air temperature was 17.7 °C, a significantly higher value than the historical mean for central Wielkopolska (Fig. 3). During the study period there were 30 days with an average temperature > 20 °C, and 30 days with a maximum temperature > 30 °C. The absolute maximum temperature for this period was 38 °C (June 30th).

The total rainfall of 392.5 mm during the study period was higher than the historical mean (310 mm). Rainfall was the most intensive in June and July. May, the first half of July and August were dry (Fig. 3). The winter preceding the study period was snowy, which compensated for the low rainfall in the spring.

The wind was different from the ones normally prevailing in Poland (westerlies) (Fig. 4), NW, SE and SW winds dominated. Such a distribution of wind directions, in combination with the experimental field layout, had a significant impact on the soil humidity and temperature in the study area.

Soil humidity varied widely in the study area. This was due on the one hand to the snowy winter (accumulated water in the snow cover close to the shelterbelt), on the other to the impact of the shelterbelts on wind speeds and in consequence on soil evaporation. There were two soil humidity maxima: one quite close to the shelterbelt adjoining the western edge of the field (i.e. in the direction of the prevailing winds), the other about 100 m from the shelterbelt. The shelterbelt along the southern edge of the field also had an influence, manifested by the greater humidity in the southern part of the study area. In the northern part, unprotected by shelterbelts from southerly winds, there was no such maximum (Fig. 5).

Soil temperature increased regularly from 17.5 to 19.3 °C from the shelterbelt to the centre of the field (Fig. 6).
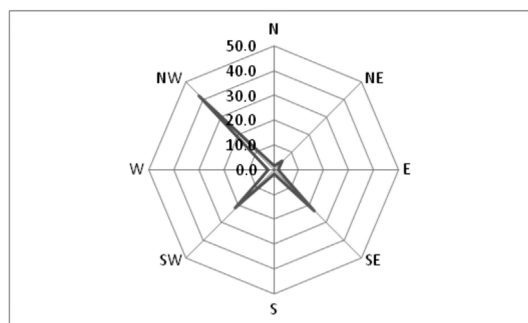
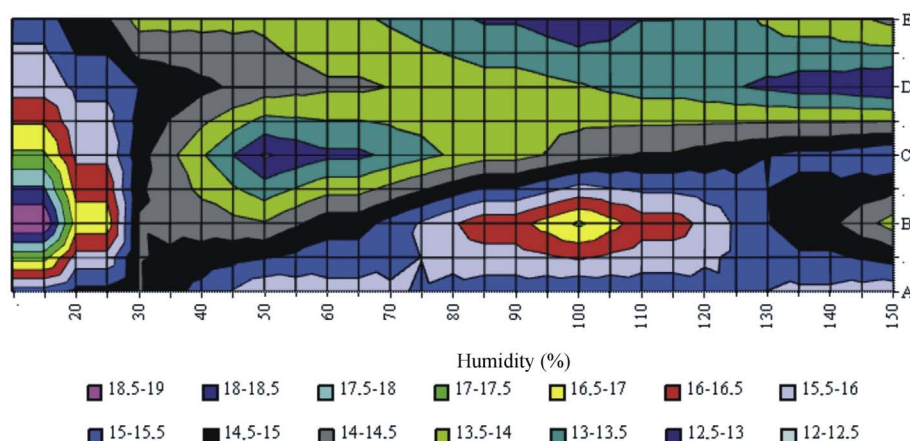**Fig. 4.** Wind distribution in the study area.

Fig. 5. Average soil humidity in the study area (June 19th – September 8th).

3.2. Maize biomass and total net primary production

Maize development was congenial with the common pattern of growth [69].

The above-ground biomass of maize increased approximately linearly from the germination (VE) right up to the last stage of material collection (R5) and did not vary between the different parts of the study area. The biomass of vegetative organs (leaves, stems) and panicles increased only up to VE phase, reaching about 900 g m^{-2}, excluding plots located 50 m from the field edge, where it was lower. In further development phases, increase of vegetative organs was much lower, or none at all. From VE phase, the increase of biomass involved mainly cobs. The maximal biomass, reached in R5 stage, ranged from 2.4 to 2.9 kg ·m^{-2} (Fig. 7). Cobs accounted for more than 60% of the above-ground biomass. There were no differences between the plots situated at various distances from the shelterbelt, apart from the biomass of leaves during the R5 phase, which shrank as the distance from the shelterbelt to the open field increased (Fig. 8).

The below-ground biomass did not exceed 300 g m^{-2} and contributed an average of 8.0% to the total biomass (from 6.8 to 9.1% in the individual sample plots). The differences in the below-ground biomasses between the distances were statistically insignificant (P = 0.87 – Kruskal-Wallis test) and the correlation between the below- and above-ground biomass was weak and insignificant (Spearman test, r = −0.30, P < 0.6).

NPP of the maize field was extremely high, in excess of 3.5 kg m^{-2}, an unprecedented value in Poland (Table 3). The percentage of the above-ground harvest biomass (in the case of maize it is close to the agricultural yield) ranged between 74 and 82%. The percentage of weeds in the total NPP was very low and did not exceed 0.25%.

4. Discussion

The results of this study support the hypothesis that shelterbelts have a mitigating effect on soil properties such as humidity and temperature [9–11,70–72]. There was an evident increase in soil humidity over a distance from the shelterbelt equal to about six times its height (100 m), but only in the southern part of the field. This could have been due to the impact of the shelterbelt situated on the southern edge of the field and the atypical distribution of wind directions. Soil humidity was the highest quite close to the shelterbelt – this was the result of the snow that had accumulated there during the previous winter [73–78]. Ultimately, as a result of the complex factors affecting soil moisture, shelterbelts had no influence on either maize yield or maize NPP.

The biomass production level presented in this paper exceeded 3 kg m^{-2}. Such a magnitude of NPP is almost twice as high as that reported in Poland for fields with different C3 crops [63,79–86] and significantly higher than that obtained in earlier studies of maize field NPP [2,86,87]. The differences in these NPP levels are due to differences in climatic conditions. The results relating to maize NPP from studies done in different regions of Poland during 30 years are an example of the overwhelming impact of temperature on the photosynthetic production of maize (Fig. 9.).

The magnitude of maize NPP approaching the value obtained in this paper has rarely been reported, even on a worldwide scale. On intensively fertilized fields in Arkansas, NPP of maize, expressed as the quantity of fixed carbon, reached 10.4 Mg ha^{-1}, i.e. ca 2080 g m^{-2} dry mass [88], but NPP of unfertilized maize fields was significantly lower (6.2 Mg ha^{-1} i.e. ca 1240 g m^{-2} dry mass). Also, the reported quantity of carbon fixed by a maize crop in northern France only slightly exceeded 800 g m^{-2}, i.e. NPP ≈1600 g m^{-2} [89]. The results presented in
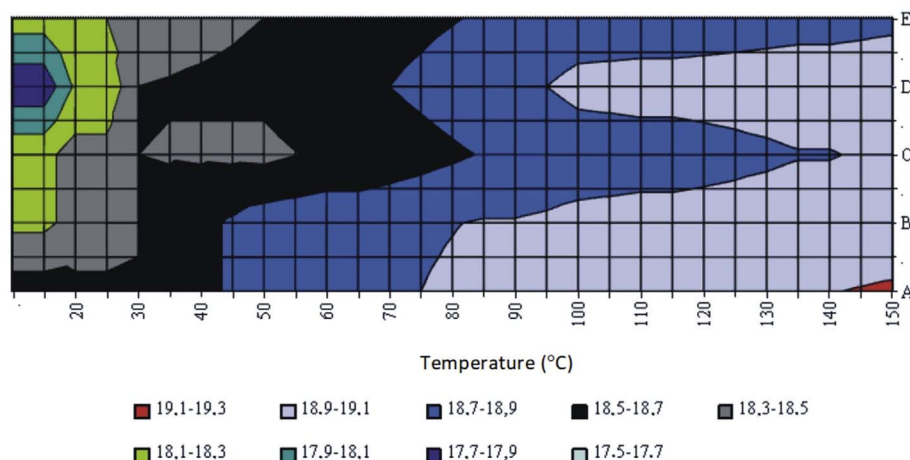

Fig. 6. Average soil temperature in the study area (June 19th – September 8th).
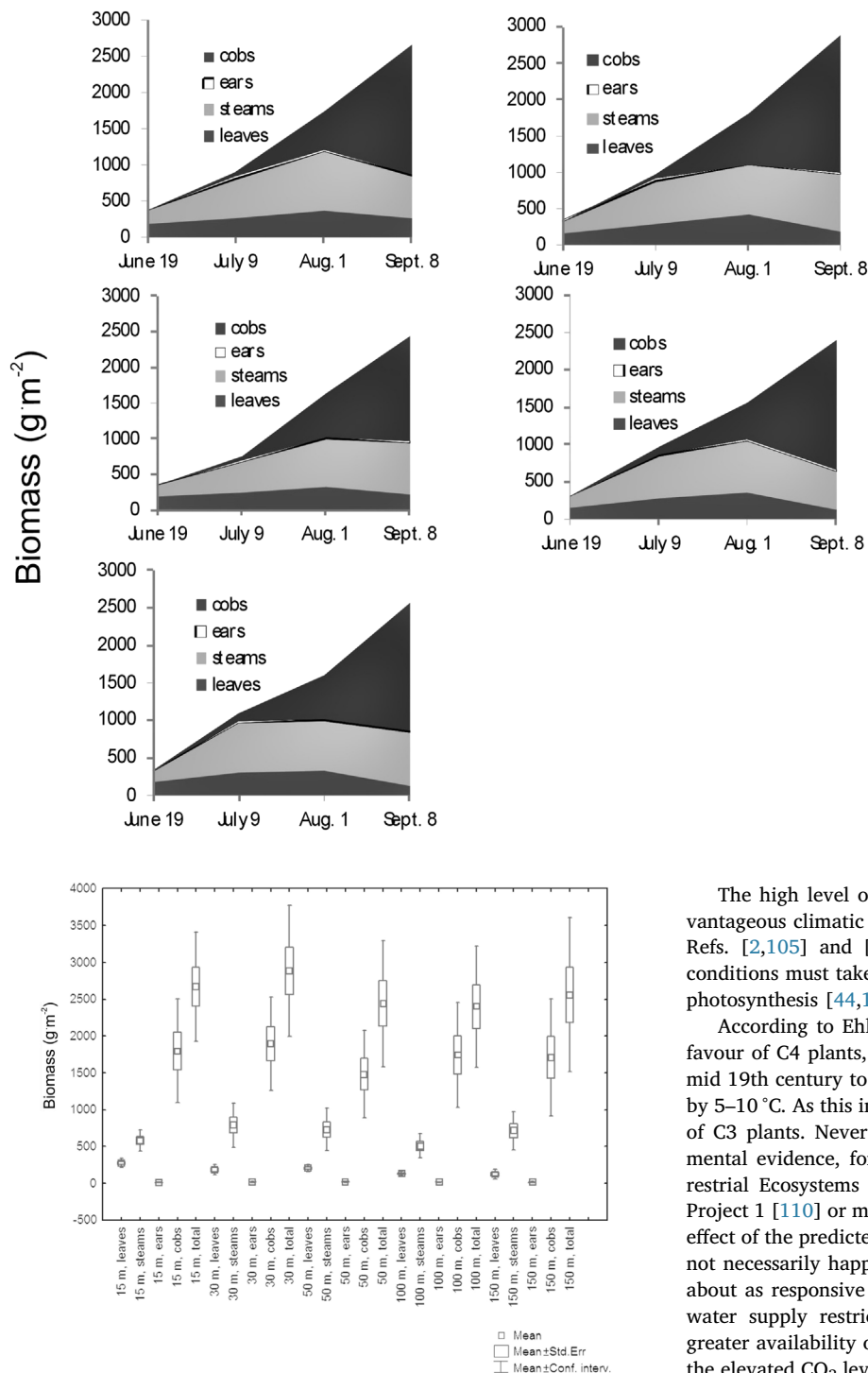
Fig. 7. Changes in above-ground biomass of maize during the growing season in different parts of the study area. A – 15 m, B – 30 m, C – 50 m, D – 100 m, E – 150 m from the western edge of the field.

Fig. 8. Differences in maize biomass in the study area during the harvest period.

The high level of NPP may have been due to the particularly advantageous climatic conditions. Such an impact was also confirmed in Refs. [2,105] and [106]. On the other hand, predictions of future conditions must take the increasing CO_2 levels into account favour C3 photosynthesis [44,107,108].

According to Ehleringer's model [109], for the balance to shift in favour of C4 plants, the increase of CO_2 level that has occurred since mid 19th century to the present would require a temperature increase by 5–10 °C. As this increase is much lower, we should expect favouring of C3 plants. Nevertheless presented results as well as other experimental evidence, for example the review of Global Change and Terrestrial Ecosystems (GCTE), Pastures and Rangelands Core Research Project 1 [110] or modelling [111], indicate that the less advantageous effect of the predicted increase of CO_2 on C4 compared to C3 species is not necessarily happening in ecosystems. The growth of C4 species is about as responsive to CO_2 concentration as that of C3 species when water supply restricts it. Additionally, in water-limited systems, a greater availability of soil moisture later in the growing season due to the elevated CO_2 level may favour the C4 species [112]. Therefore, the increase of temperature and CO_2 level is not a sufficient explanation for this phenomenon. Any analyses need to take into account a factor not included in Ehleringer's model: water availability [87,113,114]. Support for this conclusion comes also from the review made by Ref. [34] which indicates the balance shift towards C_4 plants. Moreover, higher CO_2 levels do have an indirect positive impact on biomass production by C4 plants, because they improve WUE [34]. An experiment carried out by the author, in controlled conditions [115] showed that the impact of CO_2 concentration shift on NPP of C3 (rice) and C4 (maize) crops was similar, if only temperature increased simultaneously. This view is supported by Ref. [87]. Hence, there is no evidence for the suggestion that C3 plants may out-compete C4 plants and thereby replace them in the future due to a higher CO_2 concentration. On the

this paper are also significantly (twofold) higher than most NPP recorded worldwide for crop fields as well as natural and semi-natural ecosystems [65,90–96]. Higher NPP have been reported only in the tropical zone [97–99] and in a few studies carried out in swamp ecosystems [98,100–102].
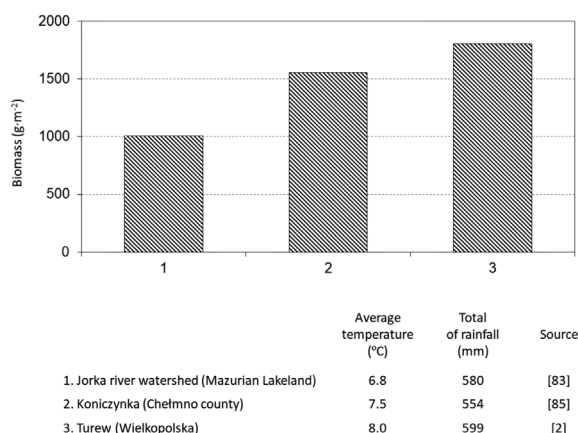
The ratio of below-ground to above-ground parts in NPP used in this paper was low in comparison with literature data [86,103] and similar to that obtained in earlier studies of maize production in this region of Poland [2] but does not confirm the change of below-ground production with increasing temperature, as reported in Ref. [2] or in Ref. [104].

Table 3
Net primary production of maize field in distinguished parts of the experimental area (g·m^{-2}).

Distance from shelterbelt (m)	15	30	50	100	150	Average
Maize aboveground parts includes:	2670.29	2883.66	2440.60	2398.90	2561.05	2590.90
leaves	276.38	184.07	208.12	132.63	124.57	185.16
steams	582.16	790.10	731.82	507.83	712.26	664.84
panicles	12.96	15.46	18.50	14.93	14.98	15.36
cobs	1798.79	1894.03	1482.16	1743.50	1709.24	1725.54
weeds	2.39	6.01	3.10	2.07	8.15	4.35
Dead parts	80.72	373.04	161.03	160.93	219.11	198.97
litter	18.47	27.47	25.72	31.94	21.06	24.93
Decomposition of ab. parts	260.00	92.07	213.64	363.13	323.46	250.46
ANPP	3011.85	3356.76	2825.76	2931.80	3099.06	3045.05
Living roots	209.17	231.85	219.87	239.75	188.28	225.25
Dead and decomposed roots	23.82	55.25	16.30	22.16	20.89	27.85
NPP	**3244.85**	**3644.65**	**3061.94**	**3193.71**	**3308.23**	**3290.68**

	Average temperature (ºC)	Total of rainfall (mm)	Source
1. Jorka river watershed (Mazurian Lakeland)	6.8	580	[83]
2. Koniczynka (Chełmno county)	7.5	554	[85]
3. Turew (Wielkopolska)	8.0	599	[2]

Fig. 9. Comparison of maize field NPP in some regions of Poland, with different climatic conditions.

other hand, the impact of CO_2 concentration on C4 plant growth increase is plainer at less-than-optimal temperatures and disappears with increasing temperatures [116].

An increase in biomass production does not automatically mean an increase in agricultural yield. Heat stress may become an important factor seriously limiting maize yields [117,118], but this effect should not have a significant impact on maize cropping for silage or for biofuels. A high level of biomass production stimulated by global climate changes, appropriate relations between above- and below-ground biomasses and the low rate of biomass death during the cropping season make maize, and other C4 plants, good substrates for biofuel production [119] Publications focusing on production of ethanol from biomass suggest that maize stover could be very useful for this process [120–122]. Maize has also been reported as the most useful crop for biogas production [53,123,124]. Furthermore, maize has a higher dry matter content and a better C: N ratio [53] than other crops.

5. Conclusions

1 The unique weather conditions in 2012 provided a good opportunity for predicting changes in soil conditions and NPP levels, anticipated as a result of global climatic changes in the temperate zone.
2 Results obtained in the presented paper, supported by some of literature data, suggest that NPP level in Poland is supposed to increase during the course of climate change, since the conditions for the more productive C4 plants will improve.
3 As a consequence of climate change, we should expect significant changes in crop structure, for example, a higher proportion of maize cropping for silage or biofuels in the temperate climate zone.

References

[1] R.R. Nemani, C.D. Keeling, H. Hashimoto, W.M. Jolly, S.C. Piper, C.J. Tucker, et al., Climate-driven increases in global terrestrial net primary production from 1982 to 1999, Science 300 (5625) (2003) 1560–1563.
[2] Z. Bernacki, Spatial differentiation of primary production and decomposition of organic matter in agricultural landscape on the example of gen, Dezydery Chlapowski Landscape Park: Role of landscape structure (2012) Rozprawy i Monografie 437.Wydawnictwo Naukowe UP. Poznań; 163 pp. (in Polish with Eng. sum.).
[3] G. Esser, Sensitivity of global carbon pools and fluxes to human and potential climatic impacts, Tellus 39B (3) (1987) 245–260.
[4] S.D. Solomon, Q.M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, H.L. Miller (Eds.), Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, U.K., New York, NY, USA, 2007996pp.
[5] T.R. Wheeler, P.Q. Craufurd, R.H. Ellis, R. Porter, P.V. Vara Prasad, Temperature variability and the yield of annual crops, Agric. Ecosyst. Environ. 82 (1–3) (2000) 159–167.
[6] F. Pearce, State of the Climate – a Time for Action, WWF report (1997).
[8] M. Zhao, S.W. Running, Drought-induced reduction in global terrestrial net primary production from 2000 through 2009, Science 329 (5994) (2010) 940–943.
[9] W.T. Bagley, Agroforestry and windbreaks, Agric. Ecosyst. Environ. 22/23 (1988) 583–591.
[10] J. Grace, Plant response to wind, Agric. Ecosyst. Environ. 22/23 (1988) 71–88.
[11] L. Ryszkowski, J. Marcinek, A. Kędziora (Eds.), Water Cycling and Biogeochemical Bariers in Agricultural Landscape, ZBŚRiL PAN, Poznań, 1990187 pp. (in Polish).
[12] J.R. Brandle, L. Hodges, H.H. Zhou, Windbreaks in north american agricultural systems, in: P.K.R. Nair, M.R. Rao, L.E. Buck (Eds.), New Vistas in Agroforestry, Kluwer, Dordrecht, 2004, pp. 65–78.
[13] M. Szwed, G. Karg, I. Pinskwar, M. Radziejewski, D. Graczyk, A. Kędziora, Z.W. Kundzewicz, Climate change and its effect on agriculture, water resources and human health sectors in Poland, Nat. Hazards Earth Syst. Sci. 10 (8) (2010) 1725–1737.
[14] M. Szwed, The elements of water balance in the changing climate in Poland, Adv. Microbiol. (2015) 14967413 pp.
[15] K. Jylhä, H. Tuomenvirta, K. Ruosteenoja, H. Niemi-Hugaerts, K. Keisu, J. Karhu, Observed and projected future shifts of climatic zones in Europe, and their use to visualize climate change information, Weather Clim. Soc. 2 (2010) 148–167.
[16] A. Holsten, T. Vetter, K. Vohland, V. Krysanova, Impact of climate change on soil moisture dynamics in Brandenburg and consequences for nature conservation areas, Ecol. Modell 220 (17) (2009) 2076–2087.
[17] Z.W. Kundzewicz, V. Krysanova, I. Pinskwar, A. Habeck, F.F. Hatterman, Regional socio-economic and environmental changes and their impact on water resources on selected areas of Central and Eastern Europe, in: Z.W. Kundzewicz, F.F. Hatterman (Eds.), Natural Systems and Global Change, Research Center of Agricultural and Forest Environment PAS, Potsdam Institute for Climate Impact Research, Potsdam, Poznań, 2006, pp. 75–87.
[18] B.R. Strain, V.C. Chase, Effect of past and prevailing temperatures on the carbon dioxide exchange capacities of some woody desert perennials, Ecology 47 (6) (1966) 1043–1045.
[19] M.A. Ford, G.N. Thorne, Effect of CO_2 concentration on growth of sugar beet, barley kale and maize, Ann. Bot. N. S. 31 (4) (1967) 629–644.
[20] H.H. Rogers, J.F. Thomas, G.E. Bingham, Response of agronomic and forest species to elevated atmospheric carbon dioxide, Science 220 (4595) (1983) 428–429.
[21] C. Potvin, B.R. Strain, Photosynthetic response to growth temperature and CO_2 enrichment in two species of C_4 grasses, Can. J. Bot. 63 (3) (1985) 483–487.
[22] B. Acock, L.H. Allen, Crop responses to elevated carbon dioxide concentration, in: B.R. Strain, J.D. Cure (Eds.), Direct Effect of Increasing Carbon Dioxide on Vegetation, US Department of Energy, Springfield, 1985, pp. 55–97.
[23] F.A. Bazzaz, The response of natural ecosystem to the rising global CO_2 levels, Annu. Rev. Ecol. Systemat. 21 (1990) 187–196.
[24] J. Rozema, H. Lambers, S.C. van de Geijn, M.L. Cambridge (Eds.), CO2 and

Biosphere. Advances in Vegetation Science 14, Kluver Academic Publishers, Dordrecht, Boston, London, 1993, p. 484.

[25] R. Ceulemans, M.E. Jach, R. Van der Velde, J.X. Lin, M. Stevens, Elevated atmospheric CO_2 alters wood production, wood quality and wood strength of Scots pine (Pinus sylvestris L.) after three years of enrichment, Global Change Biol. 8 (2) (2002) 153–162.

[26] I. Nijs, I. Impens, Effects of long term elevated atmospheric carbon dioxide on Lolium perenne and Trifolium repens using a simple photosynthetic model, Vegetatio 104/105 (1993) 421–431.

[27] P.D. Jameson, J. Berntsen, F. Evert, B.A. Kimball, J.E. Olesen, P.J. Pinter Jr., M.A. Semenov, et al., Modelling CO_2 effects on wheat with varying nitrogen supplies, Agric. Ecosyst. Environ. 82 (1–3) (2000) 27–37.

[28] T.R. Wheeler, P.Q. Craufurd, R.H. Ellis, R. Porter, P.V. Vara Prasad, Temperature variability and the yield of annual crops, Agric. Ecosyst. Environ. 82 (1) (2000) 159–167.

[29] K.E.O. Todd-Brown, J.T. Randerson, F. Hopkins, V. Arora, T. Hajima, C. Jones, E. Shevliakova, J. Tjiputra, E. Volodin, T. Wu, Q. Zhang, S.D. Allisoni, Changes in soil organic carbon storage predicted by Earth system models during the 21st century, Biogeosciences 11 (8) (2014) 2341–2356.

[30] D.T. Tissue, W.C. Oechel, Response of *Eriophorum vaginatum* to elevated CO_2 and temperature in the Alaskan tussock tundra, Ecology 68 (2) (1987) 401–410.

[31] S. Diaz, J.P. Grime, J. Harris, E. McPherson, Evidence of a feedback mechanism limiting plant response to elevated carbon dioxide, Nature 364 (6438) (1993) 616–617.

[32] A.C. Finzi, D.J. Moore, E.H. DeLucia, J. Lichter, K.S. Hofmockel, R.B. Jackson, et al., Progressive nitrogen limitation of ecosystem processes under elevated CO_2 in a warm-temperate forest, Ecology 87 (1) (2006) 15–25.

[33] R.J. Norby, J.M. Warren, C.M. Iversen, B.E. Medlyn, R.E. McMurtrie, F.M. Hoffman, Nitrogen limitation is reducing the enhancement of NPP by elevated CO_2 in a deciduous forest, J. Geophys. Res. 89 (53) (2008) Fall Meet. Supl., Abstract B32 B-05.

[34] A.D.B. Leakey, E.A. Ainsworth, C.J. Bernacchi, X. Zhu, S.P. Long, D.R. Ort, Photosynthesis in CO_2 rich atmosphere, in: J.J. Eaton-Rye, B.C. Triparthy, T.D. Sharkey (Eds.), Photosynthesis: Plastid Biology, Energy Conversion and Carbon Assimilation. Advances in Photosynthesis and Respiration 34, Springer Science + Business Media. B.V, 2012, pp. 733–768.

[35] M.R. Shaw, E.S. Zavaleta, N.R. Chiariello, E.E. Cleland, H.A. Mooney, C.B. Field, Grassland responses to global environmental changes suppressed by elevated CO_2, Science 298 (2600) (2002) 1987–1990.

[36] T. Chen, G.R. van der Werf, R.A.M. de Jeu, G. Wang, A.J. Dolman, A global analysis of the impact of drought on net primary productivity, Hydrol. Earth Syst. Sci. 17 (10) (2013) 3885–3894.

[37] Z. Feng, T. Rütting, H. Pleijel, G. Wallin, P.B. Reich, C.I. Kammann, et al., Constraints to nitrogen acquisition of terrestrial plants under elevated CO_2, Global Change Biol. 21 (8) (2015) 3152–3168.

[38] R.M. Gifford, Growth pattern, carbon dioxide exchange and dry weight distribution in wheat growing under differing photosynthetic environments, Aust. J. Plant Physiol. 4 (1) (1977) 99–110.

[39] R.J. Norby, E.G. O'Neill, R.J. Luxmoore, Effects of atmospheric CO_2 enrichment on the growth and mineral nutrition of seedlings in nutrient-poor soil, Plant Physiol. (Wash. D C) 82 (1) (1986) 83–89.

[40] N. Sionit, D.A. Morten, B.R. Strain, H. Helmers, Growth response of wheat to CO_2 enrichment and different levels of mineral nutrition, Agric. J. 73 (6) (1981) 1023–1027.

[41] N.C. Bhattacharya, P.K. Biswas, S. Bhattacharya, N. Sionit, B.R. Strain, Growth and yield response of sweet potato to atmospheric CO_2 enrichment, Crop Sci. 25 (6) (1985) 975–981.

[42] B.A. Kimball, K. Kobayashi, M. Bindi, Responses of agricultural crops to free-air CO_2 enrichment, Adv. Agron. 77 (2002) 293–368.

[43] R.L. Lindroth, K.K. Kinney, C.L. Platz, Responses of deciduous trees to elevated atmospheric CO_2: productivity phytochemistry and insect performance, Ecology 74 (3) (1993) 763–777.

[44] P.S. Curtis, B.G. Drake, P.W. Leadly, W.J. Arp, D.F. Whigham, Growth and senescence in plant communities exposed to elevated CO_2 concentrations on an estuarine marsh, Oecologia 78 (1) (1989) 20–26.

[45] D.F. Patterson, E.P. Flint, Increasing effect of CO_2 and nutrient concentration, Weed Sci. 30 (1982) 389–394.

[46] J.K. Ward, D.A. Myers, R.B. Thomas, Physiological and growth responses of C3 and C4 plants to reduced temperature, when grown at low CO_2 of the last ice age, J. Integr. Plant Biol. 50 (11) (2009) 1388–1395.

[47] R.F. Sage, R.W. Pearcy, The nitrogen use efficiency of C3 and C4 plants I. Leaf nitrogen, growth, and biomass partitioning in Chenopodium album L. and Amaranthus retroflexus L, Plant Physiol. 84 (3) (1987) 954–958.

[48] W.E. Emmerich, Ecosystem water use efficiency in a semiarid shrubland and grassland community, Rangel. Ecol. Manag. 60 (2007) 464–470.

[49] A. Williams, M.C. Hunter, M. Kammerer, D.A. Kane, N.R. Jordan, D.A. Mortensen, R.G. Smith, S. Snapp, A.S. Davis, Soil water holding capacity mitigates downside risk and volatility in US rainfed maize: time to invest in soil organic matter? PLoS One 1 (2016) 11.

[50] S.L. Niu, G.M. Jiang, Y.G. Li, L.M. Gao, M.Z. Liu, Diurnal gas exchange and superior resources use efficiency of typical C4 species in Hunshandak Sandland, China, Photosynthetica 41 (2) (2003) 221–226.

[51] D.S. Kubien, R.F. Sage, C_4 grasses in boreal fens: their occurrence in relation to microsite characteristics, Oecologia 137 (3) (2003) 330–337.

[52] M.H.O.M. Wittmer, K. Auerswald, Y. Bai, R. Schaufele, H. Schnyder, Changes in the abundance of C3/C4 species of Inner Mongolia grassland: evidence from

isotopic composition of soil and vegetation, Global Change Biol. 16 (2) (2010) 605–616.

[53] M. Fugol, H. Prask, Comparison of biogas yield from three types of silage : maize, alfalfa and grass silage, Inżynieria Rolnicza 9 (134) (2011) 31–39 (in Polish).

[54] J. Szlachta, M. Fugol, Analysis of possibility of biogas production based on manure and maize silage, Inżynieria Rolnicza 5 (114) (2009) 208–275 (in Polish).

[55] M. Szymańska, J. Łabętowicz, Availability and resources of substrates for biogas production in Poland, Czysta Energia 5 (93) (2009) 48 (in Polish).

[56] K. Leja, G. Lewandowicz, W. Grajek, Bioethanol production from cellulose raw material, Biotechnologia 4 (87) (2009) 88–101 (in Polish with English sum).

[57] J. Barros-Rios, A. Romani, G. Garrote, B. Ordas, Biomass, sugar, and bioethanol potential of sweet corn, GCB Bioenergy 7 (1) (2015) 153–160.

[58] M. Nasidi, R. Agu, Y. Deeni, W. Graeme, Improved production of ethanol using bagasse from different sorghum cultivars, Biomass Bioenergy 72 (2015 Jan.) 288–299.

[59] H.B. Aditiya, T.M.I. Mahlia, W.T. Chong, NurHadi, A.H. Sebayang, Second generation bioethanol production: a critical review, Renew. Sustain. Energy Rev. 66 (2016) 631–653.

[60] M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, C.E. Hanson, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2007.

[61] A. Woś, J. Tamulewicz, The macroclimate of the Turew region, in: L. Ryszkowski, N. French, A. Kędziora (Eds.), Dynamics of an Agricultural Landscape, PWRiL, Poznań, 1996, pp. 37–44.

[62] J. Marcinek, Sols of the Turew region, in: L. Ryszkowski, N. French, A. Kędziora (Eds.), Dynamics of an Agricultural Landscape, PWRiL, Poznań, 1996, pp. 19–26.

[63] Z. Bernacki, Primary production of agrocenosis of wielkopolski, in: S. Bałazy, L. Ryszkowski (Eds.), Produkcja pierwotna, zasoby zwierząt i Wymywanie materii organicznej w krajobrazie rolniczym, ZBŚRiL PAN, 1992, pp. 57–74 (in Polish with English summ).

[64] N. Georgev, Primary production of the association Festuca pratensis – Trifolium elegans on the northern slopes of Mt Lyulin, Phytol. Balc. 12 (2) (2006) 273–277.

[65] G.S. Newman, M.A. Arthur, R.N. Muller, Above- and belowground net primary production in a temperate mixed deciduous forest, Ecosystems 9 (3) (2006) 317–329.

[66] A. Łomnicki, E. Bandoła, K. Jankowska, Modification of the Wiegert-Evans method for estimate of net primary production, Ecology 49 (1) (1968) 147–149.

[67] R.C. Wiegert, F.C. Evans, Primary production and tie disappearance of dead vegetation on an old field in South Eastern Michigan, Ecology 45 (1) (1964) 49–63.

[68] A.A. Titlianova, Research of Biological Cycling of Carbon in Biogeocenosis: Methodological Handbook Nauka Novosibirsk, (1971) 31pp. (in Russian with English sum).

[69] http://maizedoctor.org/maize-growth-stages.

[70] L. Ryszkowski, A. Kędziora, Impact of agricultural landscape structure on energy flow and water cycling, Landsc. Ecol. 1 (2) (1987) 85–94.

[71] A. Bartoszewicz, L. Ryszkowski, Influence of the shelterbelts and meadows on the chemistry of ground water, in: L. Ryszkowski, N.R. French, A. Kędziora (Eds.), Dynamics of Agricultural Landscape, PWRiL, Poznań, 1996, pp. 98–109.

[72] A. Kędziora, J. Olejnik, Heat balance structure in agroecosystems, in: L. Ryszkowski, N. French, A. Kędziora (Eds.), Dynamics of an Agricultural Landscape, PWRiL, Poznań, 1996, pp. 45–64.

[73] B. Rognerud, K. Varum, The effect of shelter belts and irrigation on water use in a dry region, Nord. Hydrol. 5 (3) (1974) 166–172.

[74] N.I. Danilov, Formation of snow cover in plantings, of different composition and structure, Lesn. Ž 2 (1992) 27–31 (in Russian).

[75] M.L. Sizemskaya, M.K. Sapanov, I.N. Olovyannikova, T.A. Sokolova, The mains results of agroforestry amelioration and desertification control in the Northern Caspian semidesert area in Russia, Proceedings of 12th International Soil Conservation Organization Conference. May 26–31, 2002, pp. 599–601 Beijing, China.

[76] T. Węgorek, R. Rybicki, Impact of structure of midfield shelterbelt on formation of snow cover, Acta Agron. (Palmira) 7 (2006) 265–273 (in Polish).

[77] S.N. Khabarov, A.A. Kanarskij, Effect of orchard protective shelterbelts on the formation of snow in plantings of honeysuckle, Vestnik Altaiskogo Gosudartvennogo Agrarnogo Universiteta 65 (2010) 25–28 (in Russian).

[78] Z. Bernacki, J. Karg, Kształtowanie się pokrywy śnieżnej w sąsiedztwie zadrzewień śródpolnych, Pol. J. Agron. 20 (2015) 24–32.

[79] C. Kukielska, Primary productivity of crop fields, Bull. Acad. Pol. Sci. Cl. 2 (21) (1973) 109–115.

[80] C. Kukielska, Studies on the primary production of the potato field, Ekol. Pol. 21 (1973) 73–115.

[81] Z. Wójcik, Productivity of sandy ryefield, Ekol. Pol. 21 (1973) 340–357.

[82] D. Pasternak, Primary production of field with winter wheat, Ekol. Pol. 22 (1974) 364–378.

[83] T. Traczyk, H. Traczyk, D. Pasternak-Kuśnierska, Primary production of cereal crops in the Jorka River watershed, Pol. Ecol. Stud. 11 (1986) 247–262.

[84] T. Traczyk, H. Traczyk, D. Pasternak-Kuśnierska, Primary production of root crops and industrial crops in the Jorka River watershed, Pol. Ecol. Stud. 11 (1986) 263–276.

[85] J. Wilkoń-Michalska, H. Dziadowiec, Primary production of the agricultural fields with winter rape *Brassica napus* L. ssp. oleifera Netz./Siusk. fo. bienis and alfalfa *Medicago media* Pers. crops, Acta Univ. Nicolai Copernici 72 (1987) 91–107.

[86] J. Wilkoń Michalska, J. Niżewska, Primary production of fields with maize crop, Acta Universitas Nicolai Copernici 80 (1992) 61–73 (in Polish with English sum.).

[87] Z. Bernacki, Changes in the balance between C3 and C4 plants expected in Poland

with the global change, Ecol. Quest. 16 (2012) 59–68.

[88] K.R. Brye, S.T. Gower, J.M. Norman, L.G. Bundy, Carbon budgets for a prairie and agroecosystems: effects of land use and interannual variability, Ecol. Appl. 12 (4) (2002) 962–979.

[89] S. Lehuger, B. Gabrielle, E. Larmanou, P. Laville, P. Cellier, B. Loubet, Predicting the global warming potential of agro-ecosystems, Biogeosci. Discuss. 4 (2) (2007) 1059–1092.

[90] D.L. De Angelis, R.H. Gardner, H.H. Shugart, Productivity of forest ecosystems studied during the IBP: the woodland data set, in: D.E. Reichle (Ed.), Dynamic Properties of Forest Ecosystems, Cambridge Univ. Press, Cambridge, 1981, pp. 567–672.

[91] L. Ryszkowski, The dissipation of energy through soil invertebrates in wheat field and meadow, in: G. Esser, D. Overdiec (Eds.), Modern Ecology: Basic and Applied Aspects, Elsevier, Amsterdam, London, New York, Tokyo, 1991, pp. 443–455.

[92] X. Xiao, J.M. Melillo, D.W. Kicklighter, Y. Pan, A.D. McGuire, J. Helfrich, Net primary production of terrestrial ecosystems in China and its equilibrium responses to changes in climate and atmospheric CO_2 concentration, Acta Phytoecol. Sin. 22 (1998) 97–118.

[93] R. Tateno, T. Hishi, H. Takeda, Above- and belowground biomass and net primary production in a cool-temperate deciduous forest in relation to topographical changes in soil nitrogen, For. Ecol. Manag. 193 (3) (2004) 297–306.

[94] Z. Bernacki, Estimation of primary production of perennial meadow in methodological aspect, Łąkarstwo w Polsce 5 (2002) 23–42 (in Polish with Eng. sum.).

[95] R.A. Mickler, T.S. Earnhardt, J.A. Moore, Modeling and spatially distributing forest net primary production at the regional scale, J. Air Waste Manage. Assoc. 52 (4) (2002) 174–185.

[96] C.W. Xiao, J.C. Yuste, I.A. Janssens, P. Roskams, L. Nachtergale, A. Carrara, et al., Above- and belowground biomass and net primary production in a 73-year-old Scots pine forest, Tree Physiol. 23 (8) (2003) 505–516.

[97] G.L. Ajtay, P. Ketner, P. Duvigneaud, Terrestrial primary production and phytomass, in: B. Bolin, E.T. Degens, S. Kempe, P. Ketner (Eds.), The Global Carbon Cycle (Scope 13), John Wiley & Sons, Chichester, 1979, pp. 129–181.

[98] M.T.F. Piedade, W.J. Junk, S.P. Long, The productivity of the C_4 grass *Echinochloa polystachya* on the Amazonian floodplain, Ecology 72 (4) (1991) 1456–1463.

[99] D.A. Clark, S. Brown, D.W. Kicklighter, J.Q. Chambers, J.R. Thomlinson, J. Ni, E.A. Holland, Net primary production in tropical forests: an evaluation and synthesis of existing field data, Ecol. Appl. 11 (2) (2001) 371–384.

[100] D.F. Westlake, Comparison of plant productivity, Biol. Rev. 38 (3) (1963) 385–425.

[101] T.A. Kopoteva, Grassy Marshes of Priamurye, Khabarovskii Kray. Biologicheskaia produktivnost travianykh ekosistem, (1988), pp. 101–109 (in Russian).

[102] W.J. Junk, M.T.F. Piedade, Biomass and primary production of herbaceous plants communities in the Amazon floodplain, Hydrobiologia 263 (3) (1993) 155–162.

[103] B. Amos, D.T. Walters, Maize root biomass and net rhizodeposited carbon: an analysis of the literature, Soil Sci. Soc. Am. J. 70 (5) (2006) 1489–1503.

[104] E.J. Edwards, D.G. Benham, L.A. Marland, A.H. Fitter, Root production is determined by radiation flux in a temperate grassland community, Global Change Biol. 10 (2) (2004) 209–227.

[105] A.D.B. Leakey, Rising atmospheric carbon dioxide concentration and the future of C_4 crops for food and fuel, Proc. Roy. Soc. Lond. B. 276 (2009) 2333–2343.

[106] L. Bremond, A. Boom, C. Favier, Neotropical C_3/C_4 grass distributions – present, past and future, Global Change Biol. 18 (11) (2008) 2324–2334.

[107] H. Poorter, C. Roumet, B.D. Campbell, Interspecific variation in the growth response of plants to elevated CO2: a search for functional types, in: C. Korner,

F.A. Bazzaz (Eds.), Carbon Dioxide, Populations and Communities, Academic Press Inc, San Diego California, 1993, pp. 375–412.

[108] H. Wang, I.C. Prentice, T.W. Davis, Biophysical constraints on gross primary production by the terrestrial biosphere, Biogeosciences 11 (20) (2014) 5987–6001.

[109] J.R. Ehleringer, E. Cerling, R. Helliker, C_4 photosynthesis, atmospheric CO_2 and climate, Oecologia 112 (3) (1997) 285–299.

[110] B.D. Campbell, D.M. Stafford Smith, A.J. Ash, J. Fuhrer, R.M. Gifford, P. Hiernaux, S.M. Howden, M.B. Jones, J.A. Ludwig, R. Manderscheid, J.A. Morgan, P.C.D. Newton, J. Nösberger, C.E. Owensby, J.F. Soussana, Z. Tuba, C. Zuo Zhong, A synthesis of recent global change research on pasture and rangeland production: reduced uncertainties and their management implications agriculture, Econ. Environ. 82 (1–3) (2000) 39–55.

[111] S.M. Howden, G.M. McKeon, L. Walker, J.O. Carter, J.P. Conroy, K.A. Day, W.B. Hall, A.J. Ash, O. Ghannoum, Global change impacts on native pastures in south-east Queensland, Australia, Environ. Model. Software 14 (4) (1999) 307–316.

[112] C.E. Owensby, J.M. Ham, A.K. Knapp, L.M. Auen, Biomass production and species composition change in a tallgrass prairie ecosystem after long-term exposure to elevated atmospheric carbon dioxide, Global Change Biol. 5 (5) (1999) 497–506.

[113] G.W. Wall, T.J. Brooks, N.R. Adam, A.B. Cousins, B.A. Kimball, P.J. Pinter Jr.et al., Elevated atmospheric CO_2 improved *Sorghum* plant water status by ameliorating the adverse effects of drought, New Phytol. 152 (2) (2001) 231–248.

[114] R.J. Oliver, J.W. Finch, G. Taylor, Second generation bioenergy crops and climate change: a review of the effects of elevated atmospheric CO_2 and drought on water use and the implications for yield, Global Change Biol.– Bioenergy 1 (2) (2009) 97–114.

[115] Z. Bernacki, A brief recapitulation of research project: influence of CO2 concentration on primary production of rice and maize crops, Fellowship Research Report 13, The Matsumae International Foundation, Tokyo, 1993, pp. 217–224.

[116] V.G. Kakani, K. Raja Reddy, Temperature response of C_4 species big bluestem (*Andropogon gerardii*) is modified by growing carbon dioxide concentration, Environ. Exp. Bot. 61 (3) (2007) 281–290.

[117] D. Deryng, D. Conway, N. Ramankutty, J. Price, R. Warren, Global crop yield response to extreme heat stress under multiple climate change futures, Environ. Res. Lett. 9 (2014) 034011(13pp).

[118] H. Xu, T.E. Twine, E. Girvetz, Climate change and maize yield in Iowa, PLoS One 11 (5) (2016) e0156083doi:10.1371.

[119] L.L. Smith, D.J. Allen, N. Jacob, J.N. Barney, Yield potential and stand establishment for 20 candidate bioenergy feedstocks, Biomass Bioenergy 73 (6) (2015) 145–154.

[120] W. Terlouw, Sustainability Assessment of Second Generation Bioethanol Production. (MSc Thesis) manuscript, Utrecht University.

[121] C.T. Buruiana, C. Vizireanu, G. Garrote, J.C. Parajó, Optimization of corn stover biorefinery for coproduction of oligomers and second generation bioethanol using non isothermal autohydrolysis, Ind. Crop. Prod. 54 (2014 March) 32–39.

[122] I. De Bari, D. Cuna, V. Di Matteo, F. Liuzzi, Bioethanol production from steam-pretreated corn stover through an isomerase mediated process, N. Biotech. J. 31 (2) (2014) 185–196.

[123] A. Kacprzak, L. Krzystek, Comparison of efficiency of biogas production from energy plants: canary grass (Phalaris arundinacea L.) and maize (Zea mays), Inżynieria i Aparatura Chemiczna 4 (2013) 330–331 (in Polish).

[124] P. Barłóg, K. Frąckowiak Pawlak, Effect of mineral fertilization on yield of maize cultivars differing in maturity scale, Acta Sci. Pol. Agric. 7 (4) (2008) 5–17.